



TITLE:

On the Structure of the Set of Gibbs States for the 2-dimensional Ising Ferromagnet (Random Systems and Dynamical Systems)

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CITATION:

HIGUCHI, YASUNARI. On the Structure of the Set of Gibbs States for the 2-dimensional Ising Ferromagnet (Random Systems and Dynamical Systems). 数理解析研究所講究録 1981, 439: 28-29

ISSUE DATE:

1981-10

URL:

<http://hdl.handle.net/2433/102801>

RIGHT:

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On the Structure of the Set of Gibbs States for the 2-dimensional Ising Ferromagnet

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Let Z^2 be a square lattice, At each point $x \in Z^2$, we put + or - spin. $\Omega \equiv \{+1, -1\}^{Z^2}$ is the set of all possible spin configurations on Z^2 . For each finite $V \subset Z^2$ and $w \in \Omega$, the interaction energy in V is given by

$$E_V^w(\sigma) = - \sum_{\langle x, y \rangle \subset V} \sigma(x)\sigma(y) - \sum_{\substack{x \in V \\ y \in \partial V}} \sigma(x)w(y), \quad \forall \sigma \in \{+1, -1\}^V$$

where $\sum_{\langle x, y \rangle \subset V}$ denotes the summation over all nearest neighbour pairs in V . ∂V denotes the boundary of V , and w is called the boundary condition.

For any $\beta > 0$, a Gibbs state (for the parameter β) of this system is a probability measure satisfying for every finite V , $\sigma \in \{+1, -1\}^V$

$$\mu(\sigma | F_{V^c})(w) = Z(w)^{-1} \exp[-\beta E_V^w(\sigma)] = P_V^w(\sigma)$$

where F_{V^c} is the σ -algebra generated by $\{w(x), x \in V^c\}$, and $\mu(\cdot | F_{V^c})(w)$ is the conditional probability of μ on V given the outside configuration w . $Z(w)$ is the normalization.

Let $\mathcal{G}(\beta)$ be the set of all Gibbs states for the parameter $\beta > 0$. Then the following fact is known.

- (a) $\mathcal{G}(\beta)$ is convex compact
- (b) There is $\beta_c > 0$ such that
 $\#\mathcal{G}(\beta) = 1 \quad \beta \leq \beta_c \quad \text{and} \quad \#\mathcal{G}(\beta) > 1 \quad \beta > \beta_c$
- (c) for $\beta > \beta_c$, there are two distinct extremal points μ^+ and μ^- such that

$$\mu^+ = \lim_{V \uparrow Z^2} P_V^+, \quad \mu^- = \lim_{V \uparrow Z^2} P_V^-$$

where $P_V^\pm(\sigma)$ corresponds to the boundary condition w^\pm ;

$$w_{\pm}(x) = \pm 1 \quad \text{for all } x \in \mathbb{Z}^2$$

The problem we asked "Are there any other extremal points for (β) , $\beta > \beta_c$?" This was paused about 10 years ago by Gallavotti and Dobrushin, and was open till last year.

Theorem (Aizenman, Higuchi)

for any $\beta > \beta_c$, we have

$$\mathcal{G}(\mu) = \{\lambda\mu_+ + (1-\lambda)\mu_- ; \lambda \in [0, 1]\}$$

Remark: In the 3-dimensional case, the above theorem doesn't hold. Dobrushin has shown an example for sufficiently large $\beta > 0$, which cannot be a convex combination of μ_+ and μ_- .

References.

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